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IONOSPHERIC MODIFICATION EXPERIMENTS

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13. ABSTRACT On March 10-11, 1971, in cooperation with the staff of the Institute of Telecommunication Sciences (ITS) of the Environmental Sciences Services Agency (ESSA) at Boulder, Colorado, a set of experiments were performed in order to investigate certain aspects of the effects of heating the ionosphere by a high power transmitter. These experiments, based on analogous laboratory experiments, consisted in exciting the ionosphere by a variety of methods using the ITS 2-megawatt transmitter and then simultaneously quick-look analyzing the reflected waves using a spectrum analyzer and recording them on analog magnetic tape for subsequent data reduction and analysis.

Experiments were performed to determine the nonlinear behavior of electrons under the pump excitation. Second harmonic emissions at $2\omega_{HF}$ were observed which could imply an anharmonic electron orbit. In the first main experiment, continuous wave (CW) excitation was used. The reflected wave modulation spectrum contained peaks at 33 and 57 Hz. These lines were interpreted to be the result of NO^+ and O^+ ion cyclotron resonances respectively. In the second main experiment the transmitter was modulated at 0, 18, 26 and 33 Hz in sequence. Some enhancement of the 33 Hz received line occurred when the transmitter was modulated at 33 Hz. When the transmitter modulation was at one of the other frequencies no such enhancement appeared. Thus, it appears that the ionosphere can be more efficiently stimulated by modulating the transmitter at 33 Hz in a doubly resonant fashion. Subsequent analysis of analog magnetic tapes, as well as other laboratory and field experiments, suggest that a still more efficient ionospheric stimulation might have occurred if we had modulated the transmitter at 57 Hz or perhaps at an ion acoustic resonance. We conclude that a systematic sequel to these preliminary experiments is indicated.

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IONOSPHERIC MODIFICATION EXPERIMENTS

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Foreward

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PUBLICATION REVIEW

This technical report has been reviewed and is approved.

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RADC Project Engineer

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RADC Contract Engineer

Summary

On March 10-11, 1971, in cooperation with the staff of the Institute of Telecommunication Sciences (ITS) of the Environmental Sciences Services Agency (ESSA) at Boulder, Colorado, a set of experiments were performed in order to investigate certain aspects of the effects of heating the ionosphere by a high power transmitter. These experiments, based on analogous laboratory experiments, consisted in exciting the ionosphere by a variety of methods using the ITS 2-megawatt transmitter and then simultaneously quick-look analyzing the reflected waves, using a spectrum analyzer, and recording them on analog magnetic tape for subsequent data reduction and analysis.

Experiments were performed to determine the nonlinear behavior of electrons under the pump excitation. Second harmonic emissions at $2\omega_{HF}$ were observed which could imply an anharmonic electron orbit. In the first main experiment, continuous wave (CW) excitation was used. The reflected wave modulation spectrum contained peaks at 33 and 57 Hz. These lines were interpreted to be the result of NO^+ and O^+ ion cyclotron resonances respectively. In the second main experiment the transmitter was modulated at 33 Hz and then, as a control for comparison, it was modulated at 0, 18 and 26 Hz in sequence. Some enhancement of the 33 Hz received line occurred when the transmitter was modulated at 33 Hz (the NO^+ resonance). When the transmitter modulation was at one of the control frequencies (i.e., frequencies at which no peaks appeared when CW excitation was used) no such enhancement appeared. Thus, it appears that the ionosphere can be more efficient ionospheric stimulation might have occurred if we had modulated the transmitter at 57 Hz (the O^+ ion cyclotron resonance) or perhaps at an ion acoustic resonance. We conclude that a systematic sequel to these preliminary experiments is indicated.

1. Background

On March 10-11, 1971, in cooperation with the staff of the Institute of Telecommunication Sciences (ITS) of the Environmental Sciences Services Agency (ESSA) at Boulder, Colorado a set of experiments were performed in order to investigate certain aspects of the effects of heating the ionosphere by a high power transmitter. These experiments, based on analogous laboratory experiments, consisted in exciting the ionosphere by a variety of methods using the ITS 2 megawatt transmitter, and then simultaneously quick-look analyzing the reflected waves using a spectrum analyzer and recording them on analog magnetic tape for subsequent data reduction and analysis. A detailed description of the experimental arrangements and the results of the data reductions follow.

2. Spectral Analysis

CW transmissions from Platteville were reflected from the ionosphere and received at Table Mountain (A4) where their low frequency modulation was detected (see Figure 1). This experiment was an extension of earlier experiments performed in collaboration with Dr. R. Cohen of ESSA. A sample of the on-line spectrum analyzer data is shown in Figure 2. The phase variation of the received signal was monitored by a pseudo-coherent FM system with an estimated coherence time of 10^3 seconds. The system was capable of detecting 10^{-3} Hz deviations at deviation rates greater than 1 Hz in a band less than 100 Hz. This signal was computer-analyzed with a resulting increase in sensitivity of 10 db.

An interesting feature of the data is the presence of 33 and 57 Hz lines. We interpret these as being the result of the presence of electrostatic ion cyclotron resonances for NO^+ and O^+ respectively. Such a resonance occurs* at the frequencies $f \gtrsim 1.2$ fci, where fci is the cyclotron frequency for the species in question. In addition to these lines, peaks at 20, 40, 70 and 80 Hz are also seen. These peaks were detected previously in collaboration with R. Cohen. No sources of these frequencies have been found to date.

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* J.M. Kindel and C.F. Kennel, J.G.R., 76, 3055 (1971).

3. Active Modulation

An active modulation experiment was performed with one of the ITS transmitters operating at one frequency, serving as the source of a test wave, and the other nine at another frequency, 40 KHz detuned from the test wave, radiating a disturbing wave with FM modulation at a number of ionic frequencies (18, 26, 33 Hz) in sequence. A sample of the spectral analyzer results is shown in Figure 3.

The enhancement of the natural oscillation at 33 Hz was sought. When the stimulating frequency was brought into coincidence with the 33 Hz line, slight enhancement, in addition to normal superposition may have occurred. We are presently studying this situation at TRW, where we have digitized recorded data corresponding to the data shown in Figure 3.

Figure 4 is the nonaveraged version of Figure 2 and was obtained by photographing the CRT hooked up to the computer at Table Mountain (A-4). The switching on and off of the 33 Hz and the 57 Hz line can be seen here. The intertrace time is 1.25 seconds.

We have further digitized our recorded data corresponding to the data shown in Fig. 3, and have employed a computer program to study the correlations between the modulating signal and the modulation on the test wave. A variation of cross-correlation at 33 Hz of 1 $\sim$ 2.5% is observable as opposed to 0.5 $\sim$ 2% variation at other frequencies. A very slight enhancement may be present.

4. Detection of Second Harmonic Emission at $2\omega_{HF}$ (ω_{HF} = pump frequency)

We have performed additional experiments in an effort to understand the basic mechanism involved. In order to understand the nonlinear mechanism by which high frequency electronic modes couple to low frequency ionic modes we have made a search for evidence of anharmonic electronic orbits which could account for the nonlinear coupling. One indication is the emission of EM waves at $2\omega_{HF}$ where ω_{HF} is the high power HF modification frequency.

5. Conclusions

We have performed a set of preliminary experiments to determine if the "double resonance" technique of highly efficient plasma modification, used quite successfully in the laboratory, could also be used in the ionosphere. In our experiment the high power transmitter was modulated at a variety of frequencies near and at the NO^+ ion cyclotron frequency (33 Hz). Some enhancement of the 33 Hz reflected line was seen when the modulation was at 33 Hz and was absent when other modulation frequencies were used. Thus, a moderate degree of success was achieved with this line. However, data processing of the analog magnetic tapes performed after the conclusion of these experiments indicates that a greater degree of success might have been achieved if modulation at the O^+ ion cyclotron frequency had been used. In retrospect this seems reasonable as O^+ is the dominant species at the altitudes being excited. Additional laboratory and ionospheric experiments* performed subsequent to these suggest that modulations in the ion acoustic range might also be fruitful. Thus, from these results we draw the preliminary conclusion that effective use of the "double resonance" technique in the ionosphere may be feasible and that a more systematic set of experiments should be performed.

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* A.Y. Wong, et al., Plasma Physics and Controlled Nuclear Fusion Research, 1, 335 (335 (1971).

A.Y. Wong and R.J. Taylor, Phys. Rev. Letters, 27, 644 (1971).

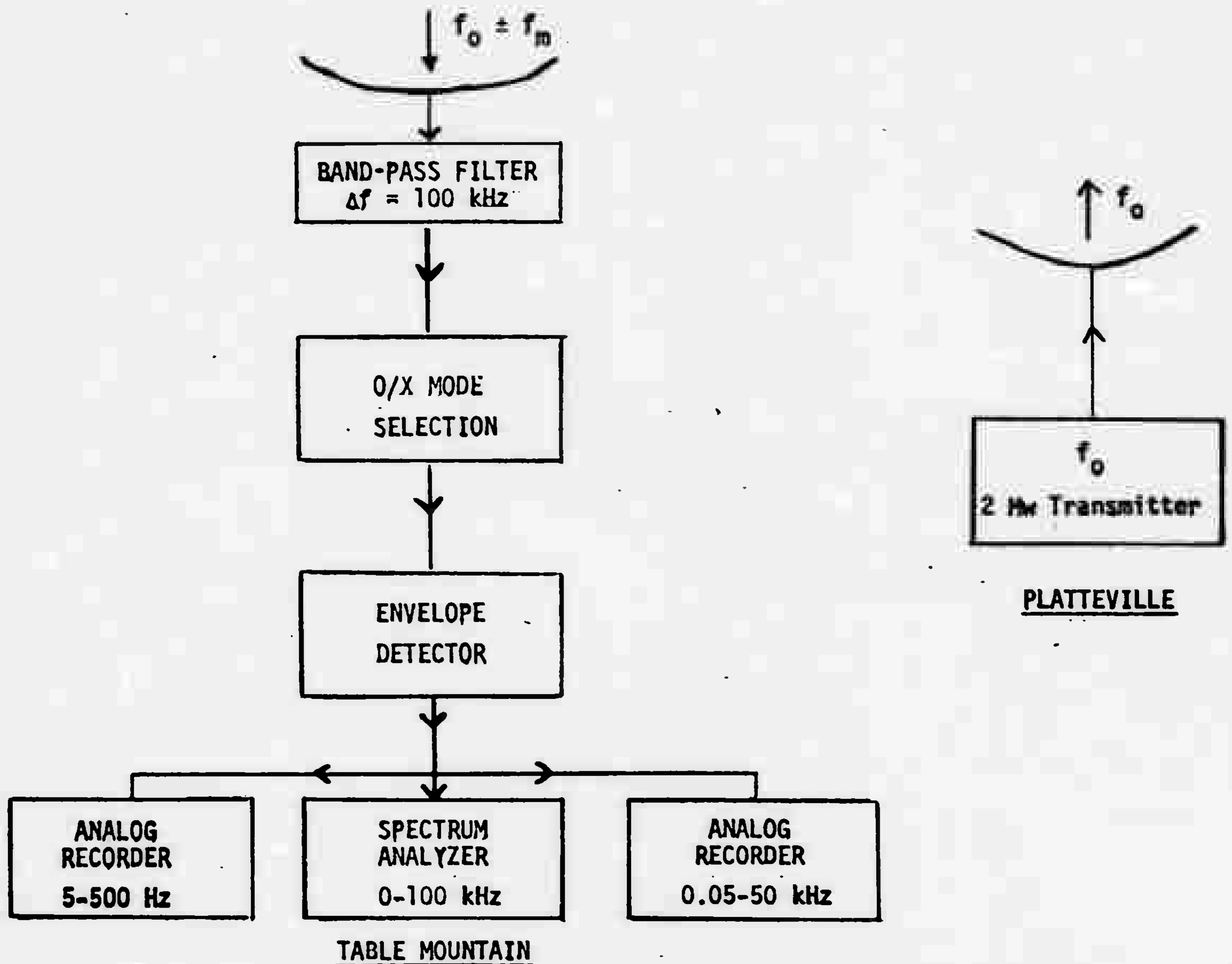
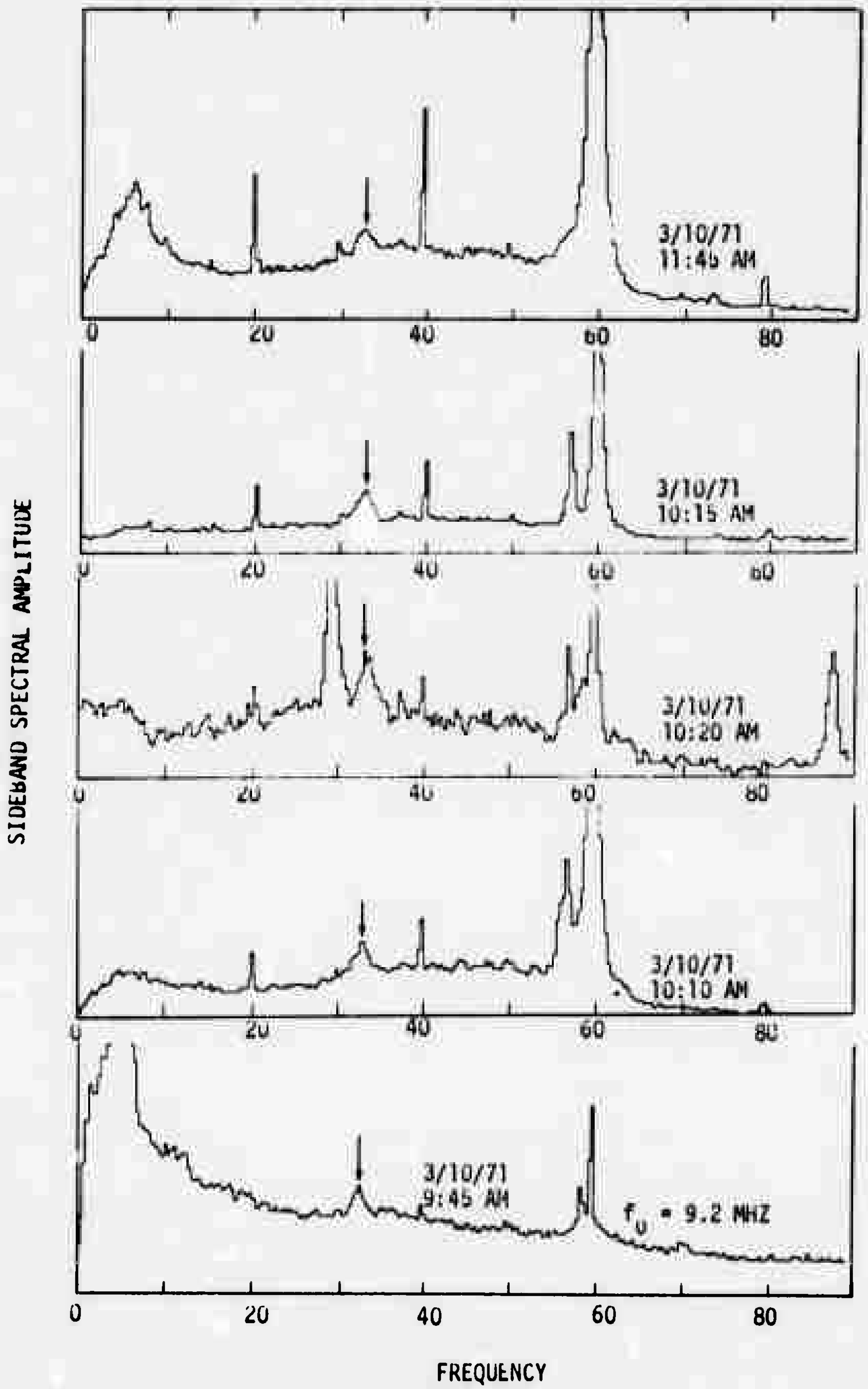
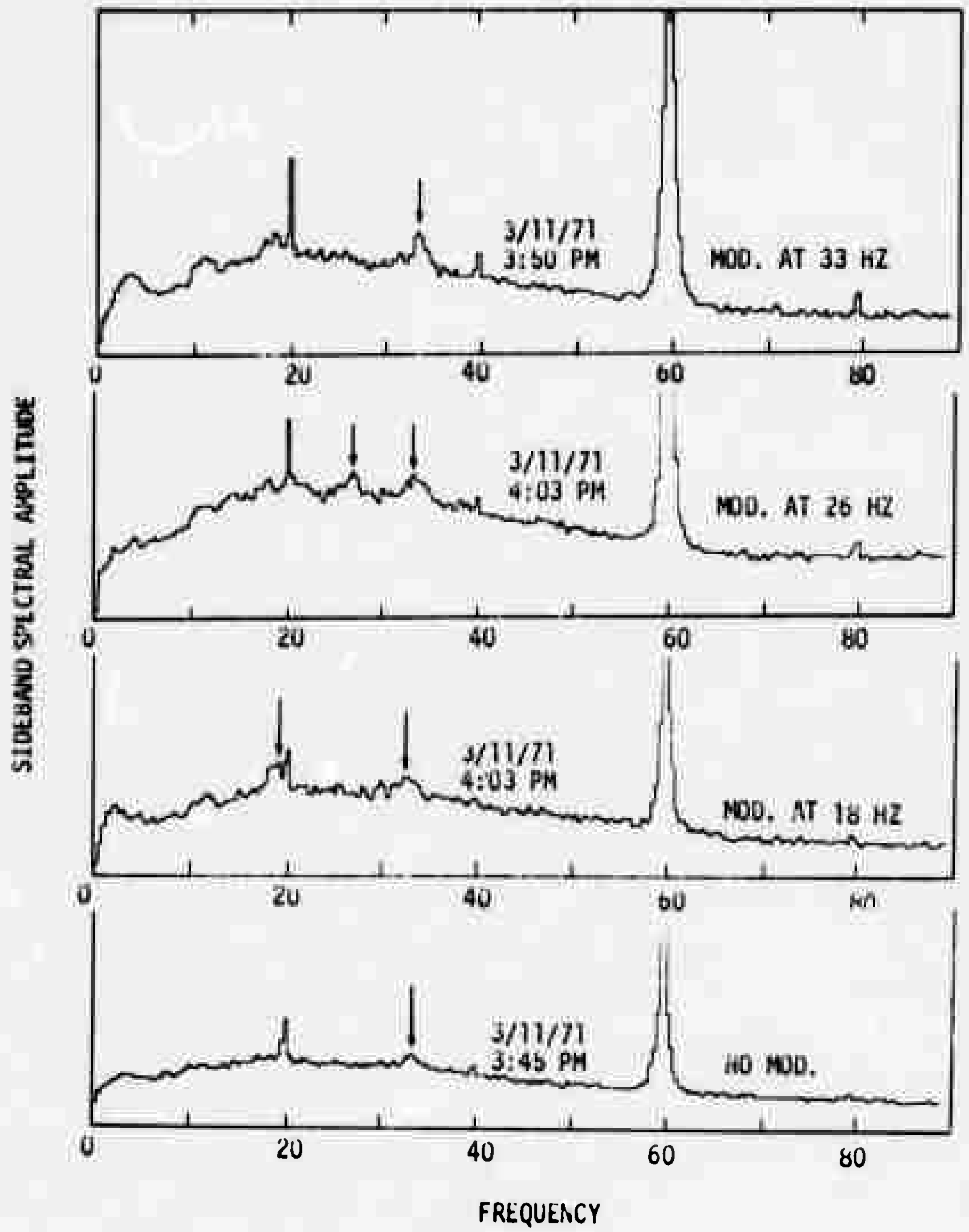


Figure 1. Determination of the excited plasma spectrum.



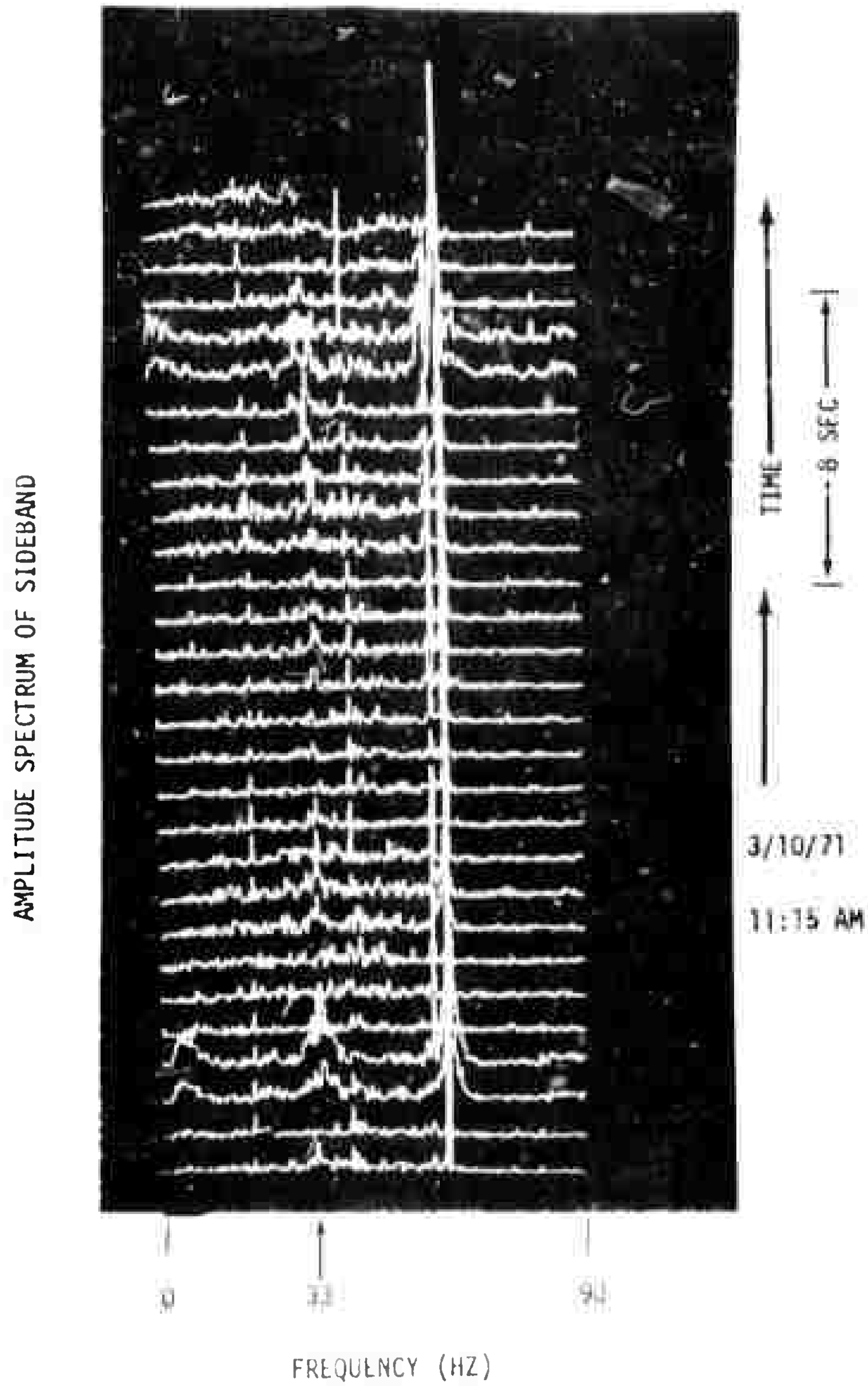
PASSIVE LISTENING

FIGURE 2



ACTIVE MODULATION

FIGURE 3



AMPLITUDE SPECTRUM OF SIDEBAND
TIME
8 SEC
3/10/71
11:15 AM
0
33
94
FREQUENCY (HZ)

FIGURE 4